EXPERIMENTAL STUDY OF PLASMA-PROPELLANT INTERACTIONS

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SUMMARY/OVERVIEW:

The use of a plasma as an ignition source has revealed several attractive benefits over conventional igniter systems, such as a shorter ignition delay, reduced temperature sensitivity of the propellant, better controlled propellant mass generation rates, and reduced susceptibility to anomalous ignition transients. However, the causes of these attractive benefits at a fundamental level are not well understood. To address the issues in this experimental program, different diagnostic tools are used, including high-speed photography, fast-response heat flux gages, and species measurements using a micro-probe mass spectrometer. Tests with homogeneous and composite propellants, including JA-2 and an azido/AP propellant, were conducted to determine the conditions required for ignition.

TECHNICAL DISCUSSION:

The electrical circuit and plasma chamber were designed and constructed in this program. The overall experimental facility includes several major components: 1) a plasma generation chamber, 2) a sample holder interfaced to a triple-quadrupole mass spectrometer, 3) an electrical circuit for discharging up to 10 kJ of electrical energy in about 0.3 milliseconds, and 4) various diagnostic components such as pressure transducers, thermocouples, IR-detectors and high-speed film camera. The electrical circuit and plasma chamber are shown in Fig. 1. In this report, we show results obtained by using the triple quadrupole mass spectrometer (TQMS), and update the progress in the design and construction of a fast-response heat flux gage.

Triple-Quadrupole Mass Spectrometry

In order to overcome the short test duration, and to increase the likelihood that propellant samples would ignite, a series of tests in which the plasma was fired into a small chamber (see Fig. 2) was performed. Pressure in the chamber reaches a maximum of approximately 3.5 MPa at 0.38 milliseconds. The velocity at which the precursor shock front of the plasma traveled through the chamber was deduced from the two pressure traces, and found to be approximately 1300 m/s. The slow decrease of pressure evident in the data results from the loss of mass through the port for sampling and from heat transfer from the hot gases to the chamber walls.

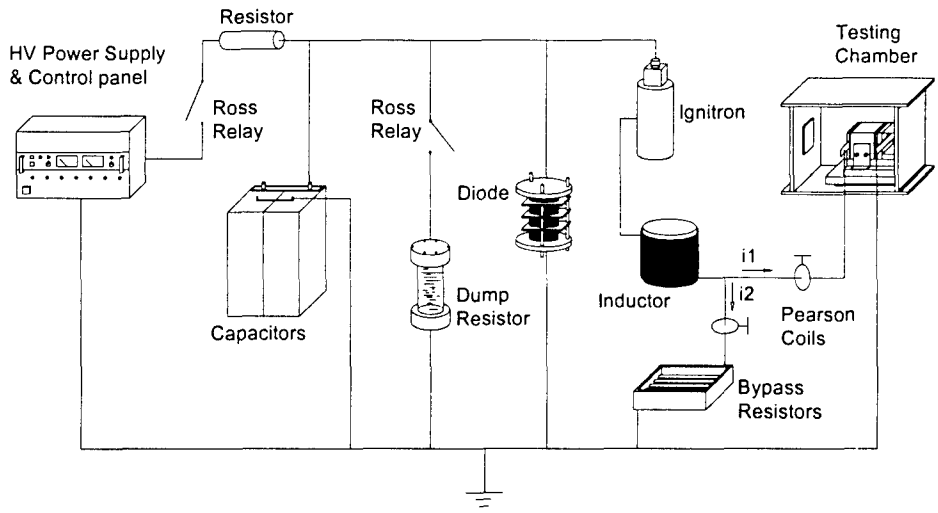

Figure 1. The electrical circuit for the Pulse Forming Network (PFN).

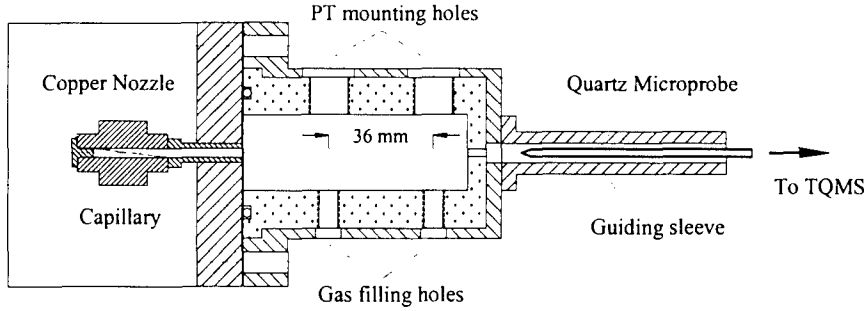

Figure 2. Setup for closed chamber testing (showing the closed chamber interfaced to TQMS and connected to the plasma chamber).

For this configuration, two significant mass signals at 26 and 28 amu were consistently measured during the micro-probe MS parent mode testing. A typical species result for a firing without a propellant sample is presented in Fig. 3. The signal at 26 amu corresponds to acetylene (C_2H_2), which is expected to be a major product from the plasma using a polyethylene capillary. The signal at 28 amu could be N_2, CO or C_2H_4, which cannot be differentiated due to the presence of air in the chamber.

This difficulty in separating the species at 28 amu led to modifications of the test chamber to allow it to be purged of air using oxygen or argon. Using oxygen was expected to sustain combustion, while eliminating the nitrogen, and argon was expected to allow pyrolysis and soot formation chemistry within the plasma to be studied, by eliminating oxygen. Results using oxygen as the ambient gas are shown in Fig. 4. Elimination of nitrogen in the ambient gas changes the trends in the signal at 28 amu. It was first detected at about 1.6 milliseconds with intensity of about 1700, reaches its peak of slightly higher than 8000 at 25 milliseconds, then decreases to 4400 at 200 milliseconds, and thereafter keeps around this level. Since the chamber was initially void of N_2, the signal at 28 amu must be CO or C_2H_4, or both.

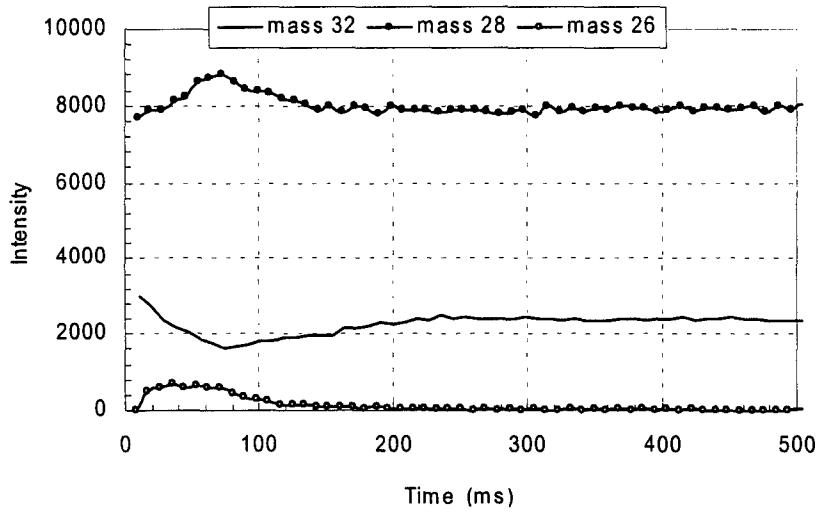

Figure 3. MPMS parent mode sampling from 4kV plasma jet generated from an 8.0mm bore PE capillary and injected into a closed chamber with air as ambient gas.

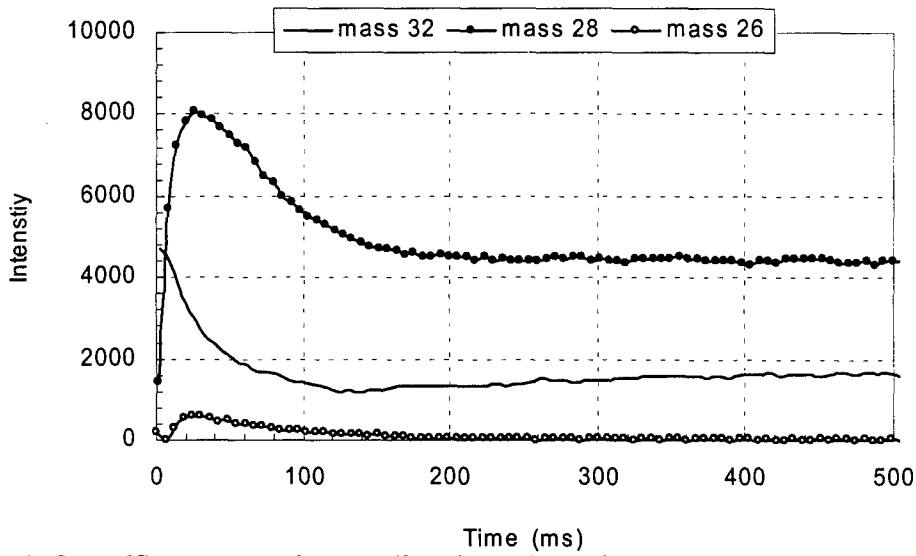

Figure 4. MPMS parent mode sampling from 4kV plasma jet generated from an 8.0mm bore PE capillary and injected into a closed chamber with O_2 as ambient gas.

Tests were then run with argon as the ambient gas, and the results are shown in Fig. 5. The results show a much larger signal for mass 26, C_2H_2, when argon is the ambient gas and also lower maximum signal at mass 28, C_2H_4 or CO. These trends indicate that oxidation is occurring in the tests with oxygen as the ambient gas, but this conclusion must be verified with daughter mode testing. In cooperation with ARL, modeling studies will be conducted to investigate the mixing and reaction in the closed chamber. Also extension of the chemical mechanism of the model to include pyrolysis and soot formation chemistry is planned to track the formation of species such as acetylene and ethylene.

The triple quadrupole mass spectrometer has undergone a major equipment upgrade, to allow molecular beam sampling. Efforts are now in progress to utilize this instrument to obtain information about highly transient species, which are present in the high-temperature plasma.

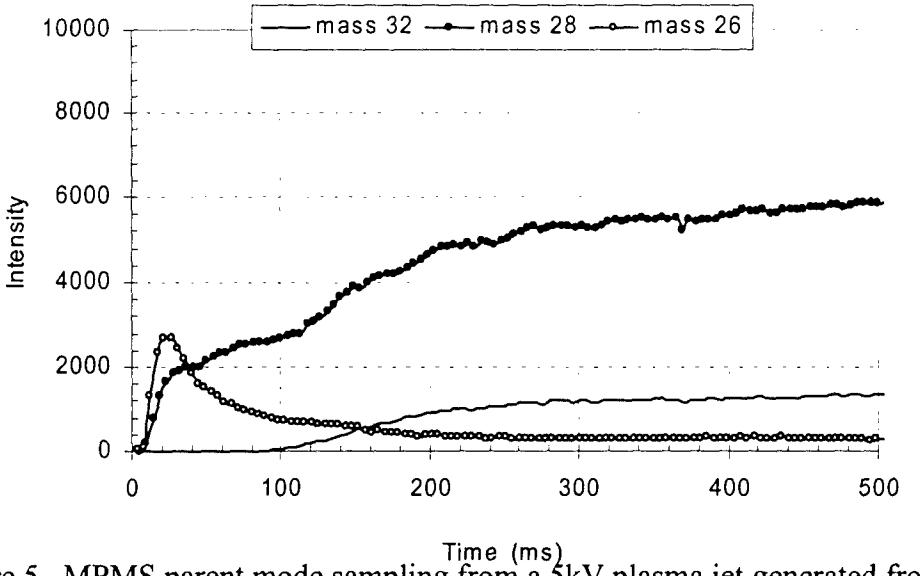

Figure 5. MPMS parent mode sampling from a 5kV plasma jet generated from a 3.2 mm bore PE capillary and injected into a closed chamber with Argon as ambient gas.

Fast-Response Heat Flux Gage

There is limited understanding of the importance of thermal radiation for achieving ignition, its in-depth heating effects, as well as the extent of in-depth chemical reactions from UV absorption. Furthermore, the overall rate of heat transfer (radiative and convective) from the plasma to the propellant's surface is also largely unknown. To ascertain the role of thermal radiation and convection, a fast-response heat flux gage is needed. This gage must also have low-noise characteristics, be readily replaceable, and be inexpensive. Such a gage has been designed and constructed. The gage itself is a thin titanium film sputtered onto a polyimide substrate. The 8 nm thick titanium film is inert and has relatively high electrical resistance. The resistance varies with temperature. By driving a constant current through the film and measuring the voltage drop, the resistance is determined. From calibration charts, the surface temperature can be deduced. An inverse heat conduction analysis is utilized to compute the heat flux variation, corresponding to the measured surface temperature variation. The gage and calibration facility have been designed and constructed. The electrical circuit that quickly must respond to resistance changes has a 500kHz frequency response, which is more than adequate. The film itself appears to very rugged and withstands a repeated, but gentle impact of a solid material. Current efforts are focused on completing the calibration of uncoated titanium films, which are highly reflective. To deduce thermal radiation, the titanium film must be coated with a flat black paint and its response assessed and calibrated. This will be followed by parametric surveys to assess the role of radiation and convection. In addition, the setup utilizes five heat flux and four pressure gages, in order to obtain a spatial variation of the heat flux.